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A SUMMARY OF THE YEAR'S WORK AT MOUNT WILSON[1]

By George E. Hale

Three outstanding events, combined with vigorous and successful work in all departments of research, render the past year a memorable one in the history of the Observatory. The first of these is the publication by Adams and his associates of the absolute magnitudes and parallaxes of 1646 stars, and the deduction from these results of the important generalizations outlined in this report. The second advance of great significance is the successful application of the interferometer by Michelson and Pease to the measurement of star diameters. No less important in its future possibilities is the establishment in Pasadena of the Norman Bridge Physical Laboratory of the California Institute of Technology and the acceptance by Dr. Robert A. Millikan of its directorship. It will be advantageous to consider the bearing of these events on the progress of the Observatory before summarizing the other activities of the year.

The two first named advances, and in a different sense the third, illustrate the value in research of the development of new instruments and methods. Prior to 1900 only 60 stellar parallaxes had been measured by the laborious methods, for the most part visual, applied up to that time. The work of Schlesinger with the 40-inch Yerkes refractor initiated a school of parallax measurers, whose efficient use of photographic methods added new and more precise determinations at such a rapid rate that the total number of trigonometric parallaxes is now about 1400. In 1915 Adams began systematic application with the 60-inch reflector of an entirely new method, which gives a parallax measure, of high precision, from the simple comparison of the relative intensities of two lines on a stellar spectrum photograph. In five years two thousand stellar parallaxes have been determined at Mount Wilson by this beautiful process, which has been applied with the 100-inch reflector to stars as faint as the 9th magnitude and could be pushed to much fainter objects. Thus, while the value of trigonometric parallaxes is by no means diminished, but rather increased, by the introduction of the spectroscopic method, the range of action and the rate of progress have been advanced in very high degree.

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[1] From the Annual Report of the Director of the Mount Wilson Observatory for the year ending August 31, 1921.

The best evidence of this advance is afforded by the conclusions based on the new measures. In complete confirmation of the earlier work of Adams and Joy, these establish beyond all doubt the validity of Russell's views on giant and dwarf stars. In their early or giant stage the stars are immensely inflated gaseous masses, so tenuous that their density may be as low as one thousandth that of atmospheric air. As they condense their temperature rises and their reddish color changes to yellow and then to white. A critical point is reached when the increasing pressure carries the mass beyond the state of a perfect gas and into the period of declining stellar life. Beyond this stage lie the denser and smaller stars known as dwarfs, of which our Sun, 1.4 times as dense as water, is one. As the shrinkage goes on, the colors that mark the giant state return, first yellow and then thru deepening shades of red as the star approaches final extinction.

Knowledge of the distances of these stars, and of their motions across and parallel to the line of sight, has rendered possible the determination of their actual motions in space. It has thus been found that the space velocities of the yellow and red stars, especially the giants, depend upon their absolute luminosities, the fainter stars moving more rapidly than the brighter ones. A decrease in brightness of one magnitude is found to correspond to an increase of about three kilometers per second in the average velocity in space. While the bearing of this result is not yet certain, it probably means that stars of small mass move more rapidly, on the average, than those of large mass. Of the many other important conclusions of this investigation given in the body of the report, one of the most significant is that the stars with large velocities, most of which are of the dwarf class, are moving toward the center of the galactic system. Thus this extensive investigation is leading to conclusions of the most fundamental significance, which are rapidly advancing our knowledge of the structure and evolution of the stellar universe.

In the last annual report the successful application of the interferometer, in the form due to Anderson, to the measurement with extraordinary precision of the close double star *Capella*, was fully explained. Merrill has since continued the measurement of *Capella* and other doubles, and Aitken has undertaken to apply this method to many of his closest pairs with the 36-inch Lick refractor. Reference was also made to a special interferometer, 20 feet in length, built for use on the tube of the 100-inch telescope, which had given sharp fringes when tested by Michelson at its full aperture on certain stars. With this instrument remarkable results have since been obtained by Pease.

On the night of December 13, 1920, when observing *Betelgeuse*, he found that the sharpness ("visibility") of the fringes steadily decreased as the interferometer mirrors were separated, until they finally disappeared completely when the mirrors were ten feet apart. Assuming the mean wave-length of the light of *Betelgeuse* to be λ5750, the angular diameter is at once found to be 0″.047, corresponding to a linear diameter of about 215,000,000 miles[2]. Since that time Pease has found the fringes of *Arcturus* and *Antares* to disappear at mirror separations of about 20 feet and 12 feet, respectively, corresponding to angular diameters of 0″.022 and 0″.040, and linear diameters of about 21,000,000 and 400,000,000 miles[2]. In the case of several other stars, even when the angular diameter is much smaller, distinct decrease in visibility has been observed when the mirrors were separated. In fact, Michelson has made very precise estimates of decreasing visibility for white stars and has devised a simple auxiliary apparatus for producing comparison fringes of known visibility. Thus, if uncertainties due to variations in seeing can be allowed for, which is still problematic, it may even become possible with the 20-foot interferometer to obtain approximate measures of stars of very small angular diameter.

The importance of this investigation is obvious, as it has already given beautiful confirmation of Russell's theory, proving the existence of giant stars of enormous size, and of mean density about one-thousandth that of atmospheric air. The new method will be developed to the fullest possible extent, and applied to all the stars that come within its range.

The third very exceptional event in the progress of the year dates in its inception from the origin of the Observatory. At Kenwood on a small scale and at the Yerkes Observatory on a larger one, the writer had utilized laboratory experiments as the necessary means of interpreting astrophysical phenomena. In this respect he simply had followed the example of Huggins,

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[2] These linear diameters may be considerably in error, chiefly because of uncertainty regarding the exact value of the parallaxes of these stars.

Lockyer, and others, gradually increasing the scale of the instrumental equipment as need and experience developed. A physical laboratory naturally formed part of the original Mount Wilson equipment, and this has proved so necessary to the interpretation of solar and stellar phenomena that it is now being advanced from a secondary to a primary place in the scheme of the Observatory. The importance of taking this step was mentioned in the last two annual reports, and progress has already been made, as the present report indicates, in building up the equipment on the necessary scale.

From the outset this equipment has been planned with special reference to the practical problem of interpreting astronomical phenomena. While it has not been thought wise to limit our physical investigations to such needs, it has seemed equally inadvisable to expand very far into the domain of the investigator who deals primarily with the fundamental laws of physics and chemistry. Thus, in our work on the Zeeman effect, begun for the express purpose of interpreting sun-spot phenomena, it has seemed best not to limit our laboratory studies simply to the lines affected in spots, but also to include other lines and to extend the range of wave-length well into the ultra-violet, beyond the termination of the characteristic spot spectrum. Similarly in the Stark effect and now in the combined effect of electric and magnetic fields on radiation, we have not adhered narrowly to the viewpoint of the astronomer, but have attacked our problems with the general interests of research in mind, without endeavoring to draw any boundary line between astronomy and physics.

Attractive as the fundamental physical aspects of these problems may be, it is nevertheless plain that their unlimited pursuit by the Observatory staff would result in a scattering of effort and in too great a departure from the paths leading to our primary objectives. It is opportune to consider in the present connection the nature of these objectives, and the best means of developing the work of the Observatory in its broader aspect.

At the outset, as the original name of the Observatory indicated, our plan was to base a general study of stellar evolution on an intensive investigation of the Sun, the results of which were expected to guide our attack on other celestial objects. The belief that increased knowledge of our single neighbor among the stars would aid in the comprehension of remote stellar objects has not been disappointed, as previous reports have shown. But in one important respect it has become necessary to enlarge the scope of our plan. The relationship between physical development, defining the successive stages in stellar life, and the various elements that determine a star's place in the structure of the universe has proved to be much more intimate than the knowledge then available had led us to recognize. Moreover, the various data, such as radial velocity, parallax, absolute luminosity, etc., thus rendered necessary for the interpretation of stellar spectra, were at hand only in the case of a few of the brighter stars. As our work progressed outward toward the remote stars, the importance of including in our scheme an investigation of the structure of the stellar universe, involving observations of stellar parallaxes, radial velocities, etc., became manifest. The results described in the present report are sufficient evidence of the necessity of this policy.

Two great problems of astronomy—the evolution of stars and the structure of the universe—have thus been attacked, but an equally important one has hitherto played only a minor part in the scheme of the Observatory. This is the constitution of matter, which in many cases may be approached even more effectively by the astrophysicist than by the physicist or chemist. Helium, rare on the Earth, but conspicuous in the solar atmosphere, was first detected there in 1868 and found in a terrestrial source in 1896. The influence of a magnetic field on radiation was visible forty years ago in the spectra of sun-spots, where a great physical experiment, open to observation with the best instruments of that time, was in progress in every spot. Faraday's last experiment, frustrated by inadequate instrumental means, was an attempt to detect the very effect that the magnetic field in spots shows so plainly. To go further back, the complete Balmer series of hydrogen lines, known in the laboratory only thru its four less refrangible members, was photographed by Huggins in the sixties in the spectra of white stars, and reproduced with difficulty in the laboratory some years later. Today we know that nebulium exists in the nebulae and in at least one star, but no one has succeeded in isolating or even detecting this gas on the Earth. Scores of other illustrations might be advanced to indicate how often the clue to fundamental physical and chemical problems may be found in the stars, but one will suffice—the remarkable relationship between ionization potentials and certain characteristic phenomena of solar and stellar spectra, pointed out by Saha and already applied by Russell in the case of sun-spots.

It is clear, therefore, that the constitution of matter, so richly and abundantly illustrated under the extreme ranges of pressure, of temperature, and of electrical excitation exhibited by the Sun and stars, should be raised from a minor to a major position in the astronomer's scheme of research. The equipment of the Mount Wilson Observatory is peculiarly adapted for this purpose, but one essential aid was lacking—the close co-operation of great physical and chemical laboratories, manned, equipped, and endowed with this chief end in view. As already suggested, such laboratories, dealing with the study of the constitution of matter, and not primarily with the interpretation of astronomical phenomena, could not properly form a part of the Observatory establishment. They would be equally useful, however, in a neighboring institution, sufficiently close at hand to permit intimate daily co-operation. Fortunately, they are now available thru the successful activities of the California Institute of Technology, which has been equally appreciative of the possibilities of combined action and has been engaged for years in the development of a general policy in which the present move plays a vital part.

The history of this institution may be of interest here. Established in 1891 as the result of a gift of fifty thousand dollars from Amos G. Throop, it was in 1904 a school of nearly five hundred pupils, chiefly of elementary, grammar school, and high school grades, tho two or three were receiving more advanced instruction. Under the presidency of Dr. James A. B. Scherer, appointed in 1908, it gradually altered its policy, gave up its work below college grade, and in 1910 began again in a new building, with only 31 students, all of them pursuing the courses of a technological school of small size but of high standards. The total assets of the Institute were still very limited, amounting, all told (buildings, site, equipment, and endowment), to approximately $580,000. The plans in view, however, were clear and definite: high standards, more and better humanistic courses than technological schools generally offer, and adequate provision for scientific research, to be ultimately the leading feature of the school. In 1916 a gift of $200,000, was received as an endowment for research in chemistry, and Messrs. Charles W. and P. G. Gates provided a building for a chemical laboratory. Dr. Arthur A. Noyes, Director of the Research Laboratory of Physical Chemistry and for two years Acting President of the Massachusetts Institute of Technology, was appointed Director of Chemical Research. For several years Dr. Noyes spent three months annually in Pasadena, but in 1919 he resigned from the Massachusetts Institute and removed permanently to California. In that year a further gift of $200,000 was received as an endowment fund to initiate research in physics, and Dr. Robert A. Millikan, Professor of Physics in the University of Chicago, was engaged as Director of Physical Research, spending three months of each year in Pasadena. During the past year several gifts to the Institute, including large additions to the endowment fund and $500,000 from Dr. Norman Bridge for a physical laboratory and library, have permitted the trustees to carry out their original plans. Dr. Millikan has accepted permanent appointment as Director of the Norman Bridge Physical Laboratory and will spend all of his time, beginning this autumn, in Pasadena. As his chief object is to continue his investigations on a larger scale and to build up an important center of research, he prefers not to accept the position of President, left vacant in 1920 by the resignation of Dr. Scherer because of ill-health. He will, however, be Chairman of the Executive Council, which will have charge of the administration of the Institute. This will consist of three members of the Board of Trustees, Mr. Arthur H. Fleming, Mr. Henry M. Robinson, and the writer, and three members of the faculty, Messrs. Millikan, Noyes, and Barrett (Secretary of the Institute).

These details are given because of the close relationship which will hereafter exist between the Mount Wilson Observatory and the California Institute of Technology. As during the past year, the members of the Observatory staff will meet weekly with the investigators of the Bridge and Gates Laboratories to hear reports on current research and discuss problems of common interest. They will also be invited to attend the courses of lectures to be given at the Institute by eminent men of science, who will include for the coming year Professor H. A. Lorentz of Haarlem and Professor Paul Epstein, formerly of Leiden, now a member of the faculty of the Institute. Furthermore, a joint study of the constitution of matter and the nature of radiation will be organized, in which the astronomical, physical, and chemical aspects of these problems will be attacked by the members of the three groups immediately concerned.

In assembling the powerful instrumental equipment required for this work, the three laboratories will act in close co-operation. Thus the provision by the Southern California Edison Company of a high tension laboratory on the campus of the Institute, to contain a 100 kw. transformer, giving approximately 1,000,000 volts, will render the acquisition of similar apparatus by the Observatory unnecessary. Needless to say, this plant will be of great service in pushing to the highest attainable limit some of the investigations described in this report and others of similar character. The Observatory will also be aided materially by having access to the powerful X-ray apparatus and the large physical library to be installed in the Bridge Laboratory. More important still, constant stimulus and enlightenment will be derived from close association with Millikan's researches on atomic structure and Noyes's chemical investigations of problems bearing directly on astronomy. The new step is therefore an epoch-making one in the progress of the Observatory.

Turning to other aspects of the year's work, we may first mention those which bear directly upon this closer alliance with physics and chemistry. For many years certain peculiarities of solar and stellar spectra have baffled all attempts at solution. As an example, it has been impossible to understand why the H and K lines, which certainly belong to calcium, an element of comparatively high atomic weight, nevertheless extend to the highest levels in the solar atmosphere, far outreaching the lines of sodium, magnesium, and other lighter elements. Dr. Megh Nad Saha, Assistant Professor of Physics in the University of Calcutta, has recently offered an explanation which appears to be generally applicable to the interpretation of many of the most puzzling phenomena of solar and stellar spectra. According to this view, the H and K lines are the enhanced lines of a calcium atom which has lost one electron, whereas the fundamental line of neutral calcium is $\lambda 4227$. In the higher levels of the chromosphere, where the ionization, which is only partial at the higher pressures of lower levels, becomes complete, neutral calcium and hence the $\lambda 4227$ line disappears, while H and K, representing the ionized atoms, remain as conspicuous lines. The D lines of sodium and the b lines of magnesium are due to the neutral atoms, which are not present at high levels, and the lines corresponding to the ionized atoms of these and other elements fail to appear because they lie in the extreme ultra-violet, with the possible exception of λ4481 of magnesium. Space is lacking to give further details, but Saha has already pointed out many possible applications of his theory, and others will rapidly develop. In evidence of this, attention is called to the important results obtained by Dr. Henry Norris Russell, Research Associate of the Observatory, who has extended the theory to the case where atoms of several kinds are present, and tested it in a preliminary study of the spectra of sun-spots. Among the interesting results of this work is the discovery in the Sun of rubidium, shown by the presence in the spot spectrum of two lines in the infra-red, as predicted by Saha. A general attack on solar, stellar, and laboratory spectra from this point of view, in which Dr. Russell and other members of the staff will take part, is being organized. In this connection it is expected that the determination of certain ionizing potentials and the study of many other fundamental aspects of the question will be undertaken at the California Institute.

Another problem calling for the joint activity of the Institute and the Observatory is that which involves the combined effect of electric and magnetic fields on radiation. The nature of this effect has been sought by the writer because of his desire to decide conclusively whether the existence of electric fields can be detected in sun-spots or other solar phenomena, and also because of the important bearing of the effect on the structure of the atom. If an electric field exists in a sun-spot, the radiating particles within it must be subjected simultaneously to the influence of both the electric field and the magnetic field of the spot. No evidence of the Stark effect has been detected in sun-spot spectra, and the weakening of the enhanced lines and other evidences of low ionization seem to indicate that a strong electric field cannot be present. It has nevertheless been thought advisable to undertake in our laboratory an investigation of the effect of the combined fields, the preliminary results of which are given in this report. In this work, done with the efficient aid of Sinclair Smith, we have fortunately had the use of the powerful coreless magnet designed by Anderson, which gives a field of 33,000 gausses with a current of 4000 amperes, and is admirably adapted for the insertion of our special quartz vacuum tubes within the uniform magnetic field. This magnet is also especially adapted for the study of the inverse Zeeman effect with the aid of an electric furnace designed by King for this purpose.

King's regular investigations of furnace spectra have dealt for the most part with the emission lines of manganese, scandium, cadmium, yttrium, neodymium, and zirconium, and the absorption spectra of iron and the alkali metals. Between λ2795 and λ6605, 270 manganese lines have been classified on the basis of their temperature variations between 1560° and 2400° C. 307 scandium lines have also been classified, and the characteristics of the enhanced lines, and of those strengthened at low temperatures, have been determined. As the enhanced lines are the only ones that are strong in the solar spectrum, it is of interest to learn that these are produced in the furnace at moderate temperatures, in some cases as low as 2250° C. The low temperature lines, absent for the most part from the solar spectrum, are naturally strengthened in spots. In the work on absorption spectra it has been found possible at the highest temperatures (3200° C) to reverse practically all the iron lines as far as λ6700. Such high temperatures have also rendered it possible to photograph the subordinate series of sodium, potassium, and calcium in absorption, giving improved wave-lengths and better values of the series constants.

Anderson's work on the absorption spectra of electrically exploded iron wires has been continued with high dispersion over the range λ2600 to λ6600. The spectra show great wealth of detail and indicate that all of the absorption lines are displaced toward the violet because of the motion of the absorbing vapor toward the observer. This displacement is, in general, greater for high temperature than for low temperature lines, and for this and other reasons it is evident that the special form of condenser needed for the development and extension of this work should be provided as soon as possible. Anderson and Smith's results on the discharge of the present large condenser through vacuum tubes are also very promising.

The publication of the wave-lengths of 1026 iron-arc lines by St. John and Babcock marks an important advance in high precision spectroscopy. Instrumental errors have been largely eliminated by the comparison of photographs taken with five different gratings and with four pairs of interferometer plates, and the agreement indicates that for most of the lines the mean wave-length is accurate to 0.001 A. The results show the serious displacements produced in the standard arc by pole effect, and the consequent necessity of taking exceptional precautions in the comparison of solar and terrestrial wave-lengths.

How essential such considerations are is well illustrated by the recent history of the attempts of various spectroscopists to detect the shift of solar lines predicted by Einstein. Several investigators, after making arbitrary assumptions and applying various corrections for pressure shift and motion in the solar atmosphere, have each confirmed Einstein's value. As a matter of fact no final conclusion seems to be warranted that is not based upon an exhaustive study of pressure shifts, variations with temperature, pole effect, motions in the solar atmosphere and other phenomena under investigation by St. John, Babcock, King and other members of the Observatory staff. Of prime importance in this work is the series of interferometer observations of the wave-lengths of lines at the center of the Sun made by Babcock and St. John with the Snow telescope. The lines selected for measurement cover a range of 2500 A, and are chosen with reference to elements of chief interest in the Sun, atomic weight, line intensity, probable level in the solar atmosphere, absence of close companions, etc. In conjunction with this investigation Babcock's interferometer study of the pressure displacements of selected iron lines under a small range of pressure is of great importance. A differential method of observation and the precautions taken to eliminate pole effect have led to results of the highest precision.

Several of the most important additions to the equipment of our Pasadena laboratory have already been mentioned. Nicholson and Pettit have also made an extended investigation of various forms of thermocouples for laboratory and astrophysical uses. The most successful of these is a tellurium-silver couple, used in vacuo, which has given excellent preliminary results. Further studies will soon determine the best arrangement of this apparatus for the purposes in view.

Closely connected with these problems is the question of the constancy in position of the telluric lines, often used as standards in the solar spectrum. A long series of very careful measures by St. John and Babock of oxygen and water-vapor lines has failed to confirm the large changes in wave-length found by Pérot. They conclude that these lines are practically constant in position, and are thus of great value as standards. St. John and Nicholson, using a dispersion of 3 angstroms per millimeter, have been able to prove beyond question that both oxygen and water-vapor lines are absent from the spectrum of *Venus*. With the high dispersion employed, the relative velocity of *Venus* and the Earth was sufficient to separate completely from the telluric lines any corresponding lines originating in the atmosphere of *Venus*. The absence of oxygen and water-vapor lines raises the question whether equal dispersion would show them in the spectra of other planets. Russell points out that St. John's proof of the absence of oxygen in the atmosphere of *Venus* is in harmony with the slight indications of oxygen in sun-spots, and the abundance of unoxidized material in volcanic gases and in the Earth's crust. A planet, if formed from the outer layers of the Sun, would contain little oxygen. This suggests that the oxygen in the Earth's atmosphere may be a product of vegetation in geological times.

From a discussion of 56 spectrograms of *Venus* and 41 of the sky Nicholson finds that the discrepancies between the wave-lengths of *Venus* and sky lines may be attributed to the effect of atmospheric refraction.

Another piece of related work is the investigation by Anderson and Babcock of the spectrum of an iron arc on Mount Wilson, as observed from the Pasadena laboratory at a distance of 7 miles, equivalent to 1.4 atmospheres. Under poor conditions of observation the spectrum has been photographed as far as λ2740, although the solar spectrum ends at λ2890. The work will be continued under better atmospheric conditions. In this connection reference may also be made to the identification by Merrill of additional air-lines in the spark spectrum in pure oxygen.

The effective wave-length of sunlight has been determined with high precision at Pasadena and on Mount Wilson by Anderson, with results indicating that it is practically constant from the zenith down to an altitude of 30°. By using this value it becomes possible to calculate with sufficient accuracy from color indices the effective wave-length of the light of any given star, as required in the reduction of interferometer measures of its angular diameter.

St. John's spectroscopic investigations of the solar rotation, which have now been continued for some years, give a mean linear velocity at the equator of 1.93 km per second, with slight irregular fluctuations. He sees no reason to believe in a progressive change from year to year, and is inclined to attribute differences between observers to systematic errors.

Daily observations of the magnetic polarities and field-strengths of all sun-spots, have been made as in previous years with the 150-foot tower telescope by Ellerman, Nicholson, Pettit, Hoge, and Benioff. Special mention should be made of the great spot of last May, which was notable for its size, its position exactly on the equator, its eruptive activity, its mixed polarity, and its connection with the brilliant auroras and violent magnetic storms which occurred while the spot was crossing the disk. All of the evidence favors the view that the terrestrial phenomena were due to the eruptions which took place repeatedly in the area surrounding the spot. Altho appearing to the eye as an ordinary bipolar group, the spot was shown by our observations of the Zeeman effect to comprise two large areas of opposite polarity in each of its chief members. As any direct magnetic effect at a distance would thus be largely annulled, the evidence against appreciable influence on the Earth, already sufficiently conclusive, is still further strengthened by this interesting case.

The writer's study of the nature of sun-spots has included the further examination of the three spot hypotheses outlined in the last report; the search for an electric field, now almost conclusively settled in the negative; and the detailed investigation of the Zeeman effect in the spot spectrum. Much evidence may be assembled in support of the deep penetration of the spot vortex, which would rule out the shallow vortex called for by the second hypothesis. The requirement that the length of the vortex shall be of the same order as the diameter of the spot, which was deduced by Störmer from his theoretical investigation of the direction of the lines of force, is strongly opposed to this hypothesis. Russell has also shown that to account for the low temperature of spots by expansion, the ascending gases must have come from depths where the temperature is probably fully 20,000° C. The detailed investigation of the Zeeman effect in the spot spectrum has involved the measurement by Dr. H. C. Wilson and Miss Mayberry of the displacements on photographs taken with Nicol and quarter-wave plate of about 6500 lines in the regions $\lambda 3900$ to $\lambda 4700$, and $\lambda 5200$ to $\lambda 5300$. The work is being continued toward the red by Miss Mayberry and the writer, about 700 lines beyond $\lambda 6100$ having been measured thus far. The peculiar displacements of the *p*-components of spot triplets mentioned in previous reports may be due in part, if not exclusively, to the mutual influence of closely adjoining lines rather than to some abnormality of the Zeeman effect, but this question is not yet settled.

Hubble's investigations have dealt especially with the galactic nebulae and the involved stars, and with non-galactic "globular nebulae", which are very numerous. These latter objects resemble spiral nebulae in spectrum and radial velocity, but even the largest of them offer no evidence of spiral structure. The smaller representatives are often indistinguishable from small spirals, but the globular type illustrated by M 87 apparently constitutes a distinct class, which is receiving special study. Many galactic nebulae and nebulous stars have also been photographed with the 60-inch and 100-inch telescopes. These nebulae apparently obscure in part the stars beyond or within them, and suggest by their forms the action of repulsive forces emanating from associated stars.

Extended nebulae and "dark" or obscuring nebulae are found to cluster about two planes—the galactic circle and the belt of bright helium stars, thus supporting the hypothesis of a local cluster, resembling the clouds of the Milky Way.

Hubble's studies of variable nebulae have been continued with interesting results. Small changes in Hind's variable nebula can apparently be attributed to variations in absorption affecting luminous regions beyond, and the same may be said of N. G. C. 2261, tho in this case the involved star appears to exercise some influence in its immediate neighborhood. N. G. C. 7629 showed marked changes while the involved star R *Coronae Australis* was brightening rapidly. Between the nights of August 14 and 16, 1920, a bright envelop, which expanded in three days from 4″ to 12″ in diameter, developed about the star. The highest observed rate of 4″ per day, assumed to represent a wave of illumination traveling outward with the velocity of light, corresponds to a distance of about 290 light years, which is in good agreement with the distance as deduced by two other methods.

Hubble's spectroscopic survey has doubled the number of known gaseous extended nebulae and more than tripled that of extended nebulae showing continuous spectra. Reference is made below to his studies of the spectra of nebulous stars and their relationship to those of other stars and nebulae.

In harmony with previous results for M 33, van Maanen has obtained definite evidence of outward motion along the arms of the spiral nebulae M 51 and M 81. As possible sources of error now seem to have been excluded, this interesting result may be considered as substantial support for Jeans's theory, which indicates that matter should be thrown off from two points of a nebula after it has been reduced by rotation to a lenticular form.

Duncan has photographed a considerable number of nebulae and star-clusters, and has detected large internal motions in M 1 (*Crab* nebula), confirming the results of Lampland. These motions are generally outward from the center, and show a maximum displacement of 2″.5 in the 11½ years interval between the plates. Three new novae in the *Andromeda* nebula and two new variable stars in the *Trifid* nebula have been found on these photographs.

The investigation of the spectra and colors of nebulous stars by Seares and Hubble has been completed for most of the known objects brighter than the 13th magnitude. Their exceptional color is strikingly illustrated by 17 faint stars involved in nebulosity near *o Persei*, which show an average color excess of over half a magnitude. In contradistinction to this effect, probably a scattering by the surrounding luminous nebulosity, Seares has found no positive evidence that the obscured areas, or "dark nebulae", in *Perseus* and *Taurus*, produce any increased redness of the neighboring stars. Hubble has photographed an abnormally high percentage of late type stars in these regions, but most of these are presumably dwarfs lying in front of the obscuring clouds, which are comparatively near us and cut off completely the light of the more distant stars.

Seares and Hubble have also made an extensive study of the correlation of stellar luminosity with spectral type and color. By plotting absolute magnitudes against spectral types or equivalent color indices some interesting relationships appear. The curve of modal values for the helium stars runs smoothly into that of the dwarfs. The Cepheids and pseudo-Cepheids of our own system present, in the mean, a correlation of color with luminosity similar to that of the Cepheids and the giant stars in globular clusters. From a corresponding correlation it is also inferred that the stars in the galactic clouds are similar in luminosity to these classes of stars. The frequency curve for stars of all types is in good general agreement with the luminosity and density functions of Kapteyn and van Rhijn.

With the aid of data bearing on absolute magnitude, Seares has determined the mean total masses of visual binaries of the various spectral types. These show the following remarkable correlation with spectral type:

B0, mass = 18; B5, 14; A0, 10; A5, 7; F0, 4.4; F5, 2.7; G0, 1.7; G5, 1.3; K0, 1.2; K5, 1.1; M, 1.0.

From F0 on the masses in this summary are those of the dwarfs. Further reference to this important investigation will be made after the completion of studies still in progress.

Photometric observations by Seares, Shapley, Hubble, Humason, and Lindblad have covered a wide range. Hubble has nearly completed the determination of the photovisual and photographic magnitudes of 250 stars associated with nebulae and nebulous clusters. Seares has given special attention to the determination of the colors of nebulous stars and the stars in galactic clouds and special fields. His color-comparisons of the Selected Areas in the +30° zone with the North Pole is half completed, and the combination of his photographic magnitudes with those of Kapteyn and van Rhijn, made with the assistance of Miss Joyner and Miss Richmond, are practically complete for areas 1 to 67. Shapley, assisted by Miss Richmond, has finished a survey of the photographic and photovisual magnitudes of about 850 stars in the *Pleiades* between magnitudes 10 and 15.5. Within this range the members of the cluster are dwarfs of absolute magnitude 5 to 10.5. In connection with the work of the International Committee on Magnitudes, Seares, as Chairman, has made a series of tests of the Mount Wilson photometric scale. These confirm earlier tests and show perfect agreement with Hertzsprung's measures for the interval between magnitudes 6 and 13. A study of the colors of 60 stars in the *Pleiades* by Seares has afforded a useful check on the method of reduction and confirmed two anomalous results suspected from other evidence.

Reference has already been made to Seares's investigations of stars in the Galaxy. From these he has derived provisional estimates for the distances of the galactic clouds, which range from 20,000 to 50,000 light years for the blue stars of apparent magnitude 14 to 15.5. These are minimum values, indicating a scale for our stellar system in harmony with that derived by Shapley from his studies of globular clusters.

Shapley has continued his work on globular clusters and related problems. The distance of the cluster N. G. C. 7006, previously found to be 220,000 light years, has been confirmed by a study of its variable stars. He has also extended his investigation of the distribution of the stars with reference to the plane of the local cluster and the galactic plane, and finds that the brighter B stars belong to the star-cloud immediately surrounding the Sun, while the fainter B stars do not.

A relationship discovered by Shapley between the light-curves of novae and certain irregular variable stars suggests that the outburst and variation of novae may result from causes such as are active in these variables. He has also examined the question whether the changes in geological climates may be due to causes analogous to those that produce the irregular *Orion* variables, where motion thru nebulosity seems to be the source of variation.

The eclipsing binary SX *Cassiopeiae*, studied in association with Mrs. Shapley, is of exceptional interest because its mean density is of the order of 0.0005 that of the Sun. This system actually consists of a very close pair of giant stars, each having a linear diameter comparable with that of *Arcturus*.

The faintest and most distant known variables are 19th magnitude stars in the globular cluster N. G. C. 7006. From an investigation by Shapley and Miss Mayberry, these objects appear to be typical short period Cepheids, some of which undergo marked light variations in a few hours.

The velocity in space of blue and yellow light, as shown by Shapley's comparative study of certain variable stars, seems to differ less than one part in a billion.

Hugo Benioff has made preliminary tests on stars of a thalofide cell, with direct current audion amplifier. The following deflections were observed with the 60-inch reflector: β *Pegasi* (vis. mag. 2.2 to 2.7, type Ma), 52 mm; ϕ *Pegasi* (vis. mag. 5.2, type Ma), 4 mm; α *Andromedae* (vis. mag. 2.2, type Aop), 5 mm. The deflections seemed to be reliable, and the work is being continued with the expectation of reaching fainter stars.

Aided by a new stereocomparator, built in our instrument shop for differential measures of high precision, van Maanen has continued his trigonometric determinations of parallaxes and proper motions. The total number of parallaxes completed to date is 144. New measures of the parallaxes of five long period variables, combined with a previously known value for *o Ceti*, give mean absolute magnitudes of +1.5 and +6.5 at maximum and minimum, respectively. Theories of variability must therefore recognize the giant character of such stars at maximum. A negative parallax was derived for the variable nebula N. G. C. 2261, in harmony with Hubble's view that its rapid apparent changes must be due to progressive variations of illumination rather than actual motion of matter.

Some of the most important of the stellar spectroscopic results of the year have already been mentioned, but much more has been accomplished in this vigorous and successful branch of the Observatory's work. The radial velocities of 253 stars have been measured by Adams and Joy, and Miss Burwell and Miss Brayton. Twenty spectroscopic binaries have been discovered, and the elements of the orbits of eight spectroscopic binaries have been completed, seven by Sanford and one by Duncan.

Much attention has been devoted to variable stars of various types. Ten cluster variables give values from +70 to −180 km for the "velocity of the system", without apparent relationship with distance from the Galaxy. Joy has determined the orbit of the variable S *Antliae*, which proves to be of the Algol type. The orbit of the Cepheid variable X *Cygni* has been investigated by Duncan on the basis of the binary hypothesis. The dark and bright lines of the Cepheid variable W *Virginis* show marked differences in the radial velocities. Remarkable changes in the spectrum of *o Ceti* were observed near minimum, including a curious asymmetry of the hydrogen lines, such as would result from an angular separation of 0″.2 of the sources producing them. Peculiar changes were observed in the spectrum of R *Scuti*. Eight long period variables with Cepheid characteristics were found to have bright lines. The spectra of the companions of *Capella*, *Antares*, and *Sirius* have been photographed, and much miscellaneous spectroscopic work has been done.

Merrill has now a total of 101 radial velocities of long-period variables, 91 of which resemble *o Ceti* while 10 have spectra of a new type. Eighty-three of these stars, of the Md (*o Ceti*) type, give from their bright lines the following values for the solar motion: V=56 km, A=274°, D=+44°. The average residual velocity of 31 km is the greatest known for stars of any spectral type. Several additional nebular lines have been found in R *Aquarii;* the displacements of the nebular and of the stellar lines are being studied. The prominent bright lines of the Md stars have been observed after maximum in the spectrum of R *Cygni*, a variable with a very different absorption spectrum. Humason and Merrill have discovered during the year more than 50 stars having the Hα line bright.

The radial velocities of 28 R type stars have been found by Sanford to range from +70 to −400 km. The algebraic mean freed from solar motion is −17 km.

Hubble has photographed the spectra of about 150 nebulous stars between magnitudes 10.5 and 14.0. Bright line stars in extended nebulae are nearly all of types Oe5 and B0, while those giving an absorption spectrum are B1 or later, averaging about B4. The central stars in six large planetary nebulae have spectra intermediate between the Wolf-Rayet and Oe5 types. Combining these results with those of Wright on smaller planetaries, we have the following sequence of types for stars involved in galactic nebulae: small planetaries, probably Wolf-Rayet; large planetaries, between Wolf-Rayet and Oe5; extended bright line nebulae, Oe5 to B0; extended nebulae with absorption spectrum, B1 to A3. This suggests the possibility that only the earliest and hottest stars may be capable of exciting bright line emission in surrounding nebulosity. Near a critical type, about B1, the bright lines fade rapidly and an absorption spectrum soon predominates, perhaps representing the reflected light of the star, as indicated by Slipher. This tentative suggestion is being thoroly tested.

The study of spectra of novae, old and recent, has been continued by Adams and Joy. Except for decreased brightness of the ring relatively to the central star, the extraordinary spectrum of *Nova Aquilae* 1918 has changed but little during the year. *Nova Cygni* 1920 showed important changes within two weeks, both in type and velocity. T *Coronae*, the nova of 1866, was found to have an absorption spectrum closely resembling that of a typical giant Ma star, with bright hydrogen and λ4686 lines.

Kapteyn has developed during the year a theory of the arrangement and motion of the entire stellar system. From his results on the distribution of stars, he derives the attraction of all the stars on any point within the system, expressed in terms of the attraction of a star of average mass. Systematic motion of the stars is necessary to produce equilibrium. Such motion, parallel to the plane of the Milky Way, is actually observed in the star-streams. A rotatory motion around the axis toward the pole of the Milky Way is therefore assumed.

The formula derived from the kinetic theory of gases for the barometric determination of altitudes is then applied to the stars lying along the rotation axis, on the assumption that their velocities are approximately distributed according to Maxwell's law. This leads to values of the average effective mass of a star ranging from 2.2 at 198 parsecs to 1.4 at 1660 parsecs.

The centrifugal forces in the plane of the Milky Way are so determined as to give the same average effective mass for regions of equal star density in this plane and on the rotation axis. The linear tangential velocities corresponding to these forces vary but little with the distance. For the greater part of the system they are practically constant and equal to 19.5 km. The direction of rotation is indeterminate. If two groups are assumed to be moving in opposite directions, their relative velocity is 39 km, which agrees closely with the observed relative velocity of the two star streams.

Altho admittedly speculative in many particulars, the value of a theory of star-streaming, giving results in harmony with observation, is obvious. Both the weak and strong points of the theory are fully discussed in a *Contribution* soon to be published by this Observatory.

Russell has extended Saha's theory of ionization in solar and stellar atmospheres to the case where atoms of several kinds are present. He finds that the proportions of ionized atoms for different elements depend only upon the temperature, tho the elements of lower ionization potential are always most highly ionized: those that have lost one electron, giving ordinary enhanced lines, and those that have lost two electrons, giving "super-enhanced" lines such as certain silicon and oxygen lines studied by Fowler.

Russell has also found Majorana's theory of the absorption of gravitation by matter to be untenable, when tested by the motions of the Moon and planets and the phenomena of the tides. Majorana's experimental results, if confirmed, may be explained as a change of mass caused by the mutual influence of two bodies.

Dr. Bertil Lindblad, of the University of Upsala, who has spent nearly a year at the Observatory, has made an important extension of the method of determining the absolute magnitude of a star from its spectrum. The continuous spectrum of A and B stars between λ3895 and λ3907, when compared with the adjoining region toward the red, is less intense in stars of low luminosity than in brighter stars. By finding the exposure ratio necessary to give equal photographic impressions for these regions the absolute magnitude is obtained. The method has been applied to the stars of several moving clusters, with results for parallax in good agreement with previous determinations.

The "cyanogen" bands have also been found to show marked increase of absorption in the more luminous stars, thus affording another measure of absolute magnitude. The effect is greatest for stars of types G5-K2 and decreases considerably toward G0 and Ma. Giants and dwarfs as faint as apparent magnitude 13.5 may be distinguished on slitless spectrograms by this method.

Mention should be made of two important pieces of work not done under the direct auspices of the Observatory. One of these is the repetition on Mount Wilson of the Michelson-Morley experiment by Professor Dayton C. Miller of the Case School of Applied Science. This fundamental investigation, which should show whether increase in altitude above sea-level has any appreciable effect on the perception of possible relative motion of the Earth and the ether, is still in the preliminary stage and will be continued by Professor Miller. The second is the initiation by Dr. H. O. Wood of the seismological work in Southern California which is being organized by the Carnegie Institution of Washington. In both cases the Observatory has been able to assist in various ways.

For many years visitors have been admitted daily to the Observatory museum of astronomical and physical photographs on Mount Wilson, and certain of the instruments have been shown by W. P. Hoge, the assistant in charge. During the past year about 10,000 visitors have seen the 100-inch telescope. We have long hoped to arrange for an open night, on which celestial objects could be shown to the public with one of the large telescopes. In view of the great height and small capacity of the observing platforms of the 100-inch telescope it is clearly unsafe to permit their use by the public. The Cassegrain focus of the 60-inch telescope is easily accessible, however, and this instrument has accordingly been arranged for use by the public on Friday evenings. Tickets are issued without charge to those who send their requests to the office of the Observatory in Pasadena.

PLANETARY PHENOMENA FOR JANUARY AND FEBRUARY, 1922

BY MALCOLM MCNEILL

PHASES OF THE MOON, PACIFIC TIME

First Quarter....	Jan. 6,	$2^{h}24^{m}$ A.M.	First Quarter....	Feb. 4,	$8^{h}52^{m}$ P.M
Full Mcon......	" 13,	6 36 A.M.	Full Moon......	" 11,	5 17 P.M
Last Quarter....	" 19,	10 0 P.M.	Last Quarter....	" 18,	10 18 A.M
New Moon......	" 27,	3 48 P.M.	New Moon.....	" 26,	10 48 A.M

During the year there will be only two eclipses, both of the Sun, as always happens under such circumstances, and neither of them visible to any extent in the United States. The first is an annular eclipse of the Sun on March 28, and the second a total eclipse[1] of the Sun on September 20-21.

Mercury is an evening star on January 1 having passed superior conjunction with the Sun late in December, but is entirely too close for naked eye view. Its distance from the Sun increases until January 29 when it reaches greatest east elongation, 18°23′. This is a very small greatest elongation since it reaches perihelion only four days later. Shortly after the middle of January it sets an hour after sunset and may be seen in the evening twilight under good weather conditions. For a few days about the time of greatest elongation it remains above the horizon about an hour and one half after sunset, and is therefore an easy naked eye object for it is then brighter than any star in the sky except *Sirius*. It passes inferior conjunction with the Sun and becomes a morning star on February 14, but remains too near the Sun for naked eye view until after the end of February, the interval between the rising of the planet and of the Sun being less than an hour. On the evening of January 29 the planet is about 3° south of the Moon.

Venus is a morning star during January but is too near the Sun for naked eye view. It passes superior conjunction with the Sun

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[1] See Dr. Campbell's note on this eclipse in the October number of these PUBLICATIONS.